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16. ABSTRACT

This paper reviews the development of technology in fine particle control. Electrostatic precipitators (ESPs), scrubbers, fabric filters, and novel devices were assessed to determine their efficiency. ESPs were found to be excellent in controlling fine particles: with an efficiency of 95% Scrubbers were found to be less efficient than ESPs, primarily when the particle size decreased: efficiency became lower than 50% at 0.5 micrometers. Fabric filters proved to be a good method of collection, showing greater than 95% efficiency for particles between.3 and 4 micrometers. Fabric filters showed less ability, however, at handling high temperatures or corrosive gas streams. Nine novel devices were tested: most showed good control of smaller particles. One problem with the novel devices was their excessive use of energy. They would, however, be efficient particle collectors where waste heat is available in large amounts.

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Electrostatic Precipitators	Particulate	13I
Scrubbers	Novel Devices	07A
Filters		14G
Fabric		11E

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Fine Particle Control Technology: Conventional and Novel Devices

Dennis C. Drehmel
U. S. Environmental Protection Agency

Fine particles (defined here as those with diameters less than 3 micrometers) can be associated with adverse health and welfare effects such as increased haze, pulmonary irritation, and bronchiogenic carcinoma.[1-4] With respect to air pollution, fine particles are not a single pollutant but a large category of pollutants of varying effects depending on size and composition. The difficulty of controlling a given source will also depend on the particulate size distribution and composition of the emission. It should be noted that throughout this paper particle size or diameter will be in terms of the aerodynamic size and control or control efficiency in terms of weight collection efficiency.

During the early development of control technology, a clear demarcation between particulate and fine particulate emissions was not made. Removal of the bulk of the mass from the gas stream was the goal and often could be accomplished with settling chambers or cyclones. As particulate control requirements became greater, scrubbers, fabric filters, and electrostatic precipitators were utilized and became conventional technology. The recent EPA-sponsored development of particulate control for stationary sources has proceeded as follows:

Dr. Drehmel is in the Particulate Technology Branch, Utilities and Industrial Power Division, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711. This is a note version of Paper No. 76-30.04 which was presented at the 69th Annual Meeting of APCA at Portland in June 1976.

1. Since important health and welfare problems can be associated with fine particles, emphasis was directed toward control of fine particulate emissions.
2. Since conventional control devices had shown some capability to control fine particulate emissions, a major effort has been directed toward characterization and improvement of conventional equipment and assessment of the collectability of dusts.
3. Since emerging technology held the potential for control directed at fine particles with higher efficiency and lower cost, EPA has sponsored a program to identify, test, and develop novel devices and concepts.

Assessment of Technology

Electrostatic Precipitators (ESPs)

Assessment of ESPs began with tests at the Gorgas Plant of Alabama Power Company. Particle concentration as a function of size was measured at the inlet and outlet of the ESP. A combination of measurement techniques was used including optical (right angle light scatter), inertial (cascade impactors), and diffusional (diffusion batteries followed by condensation nuclei counters). Results at Gorgas showed that collection efficiency as a function of particle size followed the same trend as shown for particle mobility.[5] From 10 to 1 μm the efficiency decreased from 99.9 to 95%. In the range of 0.2 to 0.5 μm the efficiency reached a minimum of greater than 90%. The efficiency then increased to almost 99% for the very fine particulate. The same minimum in collection efficiency is shown in other results recently published by EPA for an

ESP on a cement plant and for a "hot side" ESP on a low sulfur coal fired power plant.[6] For the former, the efficiency reaches the minimum at 0.4 μm and for the latter at 0.5 μm. In both cases the collection efficiency outside of the 0.1 to 1.0 μm range is greater than 98%. Inside of this range the efficiency may drop to 90%.

Several conclusions about the performance of ESPs with respect to fine particles may be drawn. First, ESPs do control fine particle emissions at selected sites where the particulate electrical properties are favorable. Overall efficiency will be greater than 99.5% and the efficiency at any size will be greater than 90%. Second, ESPs can be as effective in controlling the very fine particulate as they are in controlling coarse particles. Collection efficiencies for less than 0.1 μm size range can be greater than 98%. Lastly, the fine particles most difficult to control with an ESP are those approximately 0.5 μm in diameter. This is attributable in large part to the processes by which particles acquire charge. Coarse particles are charged by field charging; very fine by diffusion charging. Those particles of an in-between size are charged often inadequately by both field and diffusion charging and are collected less readily because they were poorly charged. To improve ESP control of fine particles, EPA began a fundamental study and limited pilot plant work on particle charging in 1974. Accurate models for particle charging have been developed and work is proceeding on design and testing of precharging chambers.

Scrubbers

Assessment of scrubbers began with a series of field tests in order to evaluate a wide variety of scrubber types.[7,8] Those tested include the following types:

1. Vale tray (Koch Flexitray).
2. Vaned centrifugal (Ducon).
3. Mobile bed (UOP Turbulent Contact Absorber [TCA]).
4. Venturi (Chemico).
5. Wetted fiber (Encort Corp.).
6. Impingement plate (Sly Impinjet).
7. Venturi rod (Environeering hydro-filter).

In evaluating the results of these tests, the cut diameter approach was used. It is generally assumed that the collection efficiency is much greater than 50% and falls to near zero as a function of decreasing particle size. The performance cut diameter is the aerodynamic diameter at which the scrubber gives 50% collection efficiency. Calvert has presented performance graphs for a number of important scrubber types.[9] Since the energy input to the scrubber has a strong influence on its performance, scrubber test results are also interpreted as a function of pressure drop. At a pressure drop of 50 cm W.C. (20 in. H_2O), typical cut diameters would be 1.2 μm for packed columns or impingment plates, 1.0 μm for a sieve plate, and 0.7 μm for a venturi. Hence, at a moderate energy input the collection efficiency of fine particles could be much less than 50% at 0.5 μm.

For all types of scrubbers tested and listed above, it was found that collection efficiency was initially high and decreased rapidly with decreasing particle size. The energy input to the scrubber affected the size at which the efficiency began its decline. Table I shows these results in terms of the cut diameter already defined and in terms of the diameter at which the efficiency falls below 80%.

A more recent assessment program which tested collection efficiency down to 0.08 μm illustrates that scrubbers have an analogous minimum in their collection curves as electrostatic precipitators have.[10] The efficiency of a TCA scrubber on a coal fired power plant decreased to 30% collection at 0.4 μm and then increased back to 97% at 0.08 μm. As with the electrostatic precipitator minimum, two mechanisms are involved. For coarse particles, collection is by an impaction mechanism; for very fine particles, by a diffusion mechanism. Since 0.4 μm diameter particles have neither a high diffusivity nor a large inertial mass for impaction, they are the most difficult to collect. To improve scrubber performance, EPA has sponsored development and demonstration of condensation effects.

Table I. Fine particle control by scrubbers.

Name	Pressure drop, cm WC	Smallest diameter collected at stated efficiency, μm 80%	50%
Koch	30	1.6	1.0
Ducon	8	1.6	1.3
UOP/TCA	30	0.7	0.35
Chemico venturi	25	0.9	0.7
Wet fiber	19	1.1	0.6
Sly Impinjet	30	1.7	1.3
Venturi rod	273	0.5	0.3

Fabric Filters

Assessment of fabric filters has proceeded with tests of two installations on utility boilers and one on an industrial boiler.[11,12] The results of these tests show greater than 95% collection at all sources in all size ranges tested from 0.1 to 4 μm. Results for each site are as follows:

1. At the Sunbury pulverized coal fired power plant with glass/Teflon bags and an air-to-cloth ratio of 2, the overall mass removal efficiency was 99.9%. The outlet loading was 0.0039 grams/m^3 (0.0017 g/dscf). The efficiency was 99% at 0.1 μm, near 98% at 0.5 μm, and above 99% at 1.0 μm.
2. At the Nucla stoker coal fired power plant with graphited glass bags and an air-to-cloth ratio of 3, the overall mass removal efficiency was 99.8%. The outlet loading was 0.0071 g/m^3 (0.0031 gr/dscf). The efficiency was 99% at 0.1 μm, 99% at 0.5 μm, and greater than 99% for 1.0 μm.
3. At the Kerr Industries stoker fired industrial boiler with Nomex bags and an air-to-cloth ratio of 3, the overall efficiency was 99.2%. The outlet loading was 0.0046 g/m^3 (0.002 gr/dscf). The efficiency was almost 99% at 0.3 μm, about 95% at 0.6 μm, and back up to greater than 98% at 2.0 μm.

These results may be compared to tests of a lead sintering machine baghouse with Orlon fabric which gave an overall mass efficiency of 99.7%.[13] The efficiency at 0.3 μm was 99.5%, at 0.7 μm 99.4%, and at 2.0 μm 99.6%. It is apparent that fabric filters are highly efficient fine particle collectors. However, the large size and difficulty to control corrosive or high temperature (>400°C) gas streams have limited applicability of fabric filters. To extend applicability of filtration, EPA has sponsored development of high velocity filtration to reduce size and research to improve fabrics and finishes.

Novel Devices

Often a device cannot be strictly categorized as a scrubber, fabric filter, or electrostatic precipitator or the device is different in some manner from conventional technology. In this event, the control unit may be tested by EPA as a novel device. The following devices have been tested:

1. Sonic agglomerator (Braxton).
2. Steam hydro scrubber (Lone Star Steel).
3. Dynactor scrubber (RP Industries).
4. Pentapure impinger (Purity).
5. ADTEC scrubber (Aronetics).
6. CHEAF (Andersen 2000).
7. Centrifield scrubber (Entoleter).
8. Gravel bed (Rexnord).
9. Electrostatic scrubber (APS).
10. Electrotube (APS).

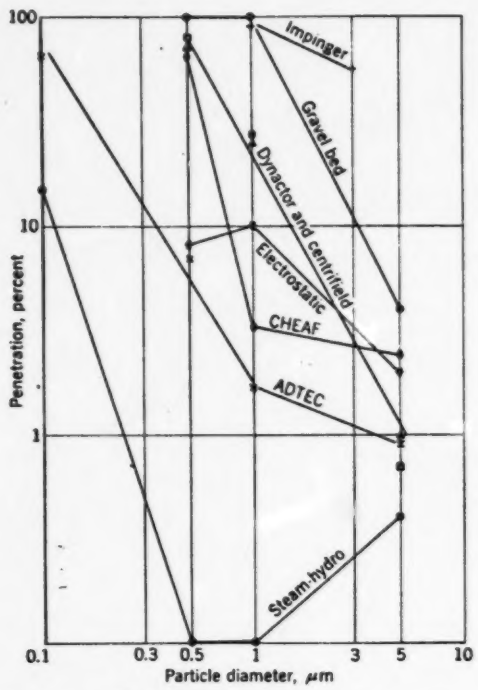

Figure 1. Particulate control by novel devices.

A detailed description of these devices is beyond the scope of this paper. One should note that many are scrubbers and all utilize water except for the gravel bed. Results for these devices are shown in Figure 1. Only the Steam-hydro (Lone Star), Aronetics, and APS scrubbers demonstrate greater than 90% removal for 0.5 μm diameter particles. A comparison of novel devices to conventional technology may be made using the cut diameter concept for scrubbers. Table II gives this comparison to venturi scrubbers with a high and low pressure drop. The Steam-hydro and ADTEC scrubbers show the best performance in this ranking and are slightly better than the high pressure drop venturi scrubber. Unfortunately, both of these scrubbers rely on the use of waste heat to provide the enthalpy to drive the scrubbers and are high energy users. When the total energy input to these scrubbers is considered, their performance is completely in line with that of the high pressure drop venturi. A similar observation may be made for other novel device scrubbers shown in Table II; that is, performance is directly related to total energy input. This does not mean that these devices do not have advantages over conventional technology. For example, if waste heat is available, the Steam-hydro and ADTEC scrubbers offer a very high particle collection efficiency.

Table II. Fine particulate control by novel devices compared to venturi scrubbers.

Name	Smallest diameter collected at 50% efficiency, μm
Impinger	3.5
Gravel bed	1.4
Venturi (25 cm WC)	0.7
Dynactor	0.65
Centrifield	0.6
CHEAF	0.53
Venturi (273 cm WC)	0.3
ADTEC	0.13
Steam-hydro	<0.1

Conclusions

Conventional control technology can be effective in controlling primary fine particulate emissions. If the ash resistivity is approximately 10^{10} ohm-cm, 90% collection at all size ranges can be accomplished by an ESP. Where space considerations allow, fabric filtration will provide greater than 95% collection at all size ranges. Emerging technology may find application in specialized circumstances; for example, where waste heat is available, high removal efficiencies at low additional energy consumption are possible.

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